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PATENT APPLICATION



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__X__ New Application; or _____ Continuation; or _____ Divisional, or _____ Continuation-in-Part (CIP) Application of prior US application No._____, filed on _____, having US Examiner _____, in Group Art Unit_____: of

Inventor(s): WILLIAM THOMPSON and ANDREW MACKIE

For (Title): SYSTEM AND METHOD OF DECODING A PACKED REPRESENTATION OF MULTIPLE PARSES

This transmittal letter has 2 total pages.

Enclosed are:

__X__ __11__ sheets of drawings, along with __30__ pages of specification, claims, and abstract.

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____ Consider as the above Statement, Please delete as inventors for this application the following inventors named in the prior application: _____

_____ Foreign priority to _____ Patent application having serial number _____, and a filing date of_____ is hereby claimed under 35 USC 119.
_____ A copy of the priority document is included herewith.

_____ An Assignment Transmittal Letter and Assignment of the invention to MOTOROLA, INC.

_____ An Information Disclosure Statement (IDS), with _____ PTO-1449, and ____ citation copies.

_____ Petition For Extension of Time for parent application of the present Continuation/Division/CIP application

_____ Print EFS Inventor Information Sheet(s).

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_____ Preliminary Amendment

_____ Please cancel filed claims _____.

_____ Incorporation by Reference (for Continuation/Division application) The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.

_____ Since the present application is based on a prior US application, please amend the specification by adding the following sentence before the first sentence of the specification: "The present application is based on prior US application No. _____, filed on_____, which is hereby incorporated by reference, and priority thereto for common subject matter is hereby claimed."

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By: _____

James E. Gauger
for Applicant(s)
Registration No. 38,154
MOTOROLA, INC.
Phone: (847) 576-0065
Fax: (847) 576-3750

# SYSTEM AND METHOD OF DECODING A PACKED REPRESENTATION OF MULTIPLE PARSES

## FIELD OF THE INVENTION

The present invention generally relates to natural language parsing, and more particularly to natural language parsing that is suitable for automatic speech recognition.

## BACKGROUND OF THE INVENTION

In general, a semantic representation is generated from a natural-language utterance by the following process. The natural-language utterance is processed by a speech recognizer, which is coupled to a lexicon containing a plurality of words of the natural language. The speech recognizer outputs a word graph, containing at least one, and normally multiple words from the lexicon that is hypothesized to correspond to the natural-language utterance. The word graph is input into a parser, which is coupled to a grammar for the natural language. Using this grammar, the parser constructs a parse forest during the parse.

The parse forest is then inputted into a semantic interpreter, which is coupled to a knowledge base. The semantic interpreter processes the parse forest according to a predetermined semantics and outputs at least one semantic representation corresponding to the natural language utterance.

One problem with this process is that multiple word hypotheses in the word graph combined with ambiguities in the grammar may yield a large number of parses. Thus, the parse forest may become unmanageably complex. Although techniques exist to ameliorate this problem, they may remove structures that may later turn out to be useful. Alternatively, if the parse forest is packed during the parsing process, the problem of its complexity is only deferred, since an accurate and efficient means is still required to unpack the forest for processing by the semantic interpreter.

Primarily, it would be desirable to provide a method of decoding or unpacking the individual parses stored in the packed representation of a

parsed word graph to yield a forest of parse trees, preferably in an order that represents their probable correctness or usefulness according to a predetermined metric.

## BRIEF DESCRIPTION OF THE DRAWINGS

**FIG. 1** is a schematic representation of a speech recognition system including a packed representation decoding module in accordance with the invention;

**FIG. 2** is a flow chart of an embodiment of a top-level unpacking process in accordance with the invention;

**FIG. 3A** is a flowchart of one embodiment of the "get next edgenode" process in accordance with the invention;

**FIG. 3B** is a schematic representation of the states of the self-embedding operation as defined for forest objects;

**FIG. 3C** is a schematic representation of the states of the N-fold replication operation as defined for forest objects;

**FIG. 4** is a schematic representation of a packed forest;

**FIG. 5** is a schematic representation of the packed forest of **FIG. 4** with most probable and alternative parses;

**FIG. 6** is a schematic representation of the unpacking process of the packed forest of **FIG. 4**;

**FIG. 7** is a schematic representation of an unpacked forest resulting from unpacking the packed forest of **FIG. 4**;

**FIG. 8** is a schematic representation of a word graph output from a speech recognizer; and

**FIG. 9** is a UML diagram of a preferred embodiment for the forest and its related classes.

## DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENTS

Referring to **FIG. 1**, a schematic diagram of a system 10 for encoding and decoding multiple parses is shown. The speech recognizer (SR) **11** produces output or word graph **12**, which is sent to parser **14**. A grammar **16** is used to produce a packed representation **18** of the multiple parses. A preferred method and system for encoding the packed representation **18** is disclosed in U.S. Application No. _____ entitled "Method, Device and System For Generalized Bidirectional Island-Driven Chart Parsing," the entire disclosure of which is incorporated herein by reference. The packed representation **18** is then unpacked using the unpacking module **20** to create an unpacked forest **22** which is input to a semantic interpretation module **24**. A flow chart of a preferred embodiment of the unpacking module **20** is presented in **FIGS. 2** and **3A**. The unpacking module **20** may include any suitable computer programming code using any conventional programming language, and may be stored on any conventional computer readable medium.

When the parser **14** is run in multiple-parse mode, the resulting parses are generated and stored in a packed representation **25**, a simplified example of which is shown in **FIG. 4**. The packed representation **25** encodes: (1) a set of grammatical paths through the word graph sent to the parser **14** by the SR **11**, and (2) the corresponding syntactic structures assigned to these paths by the parser **14** (the syntactic structure assigned to a path allows it to be analyzed semantically by the semantic interpretation module, which operates on the parse trees constructed by the parser). The subgraph of the SR word graph that contains the set of grammatical paths will be referred to as the "active word graph."

A simplified representation of a SR word graph **28** corresponding to the packed representation in **FIG. 4** is shown in **FIG. 8**; the heavy lines **26** represent the "best path" through the word graph **28** (corresponding to the terminals of the most probable parse tree), while the heavy lines **26** together with the solid lines **27** represent the active word graph and the dashed lines

**29** represent paths not selected by any parse. It is important to note that the active word graph may contain paths that are not selected with respect to the parses stored in the packed representation **25** (i.e., they do not have valid syntactic structures and thus cannot be analyzed semantically); in the example shown in **FIG. 5**, it can be seen that the path (w0, w1, w4, w6) does not correspond to a valid parse, even though it occurs in the active word graph.

The parser's packed representation **25** (see **FIG. 5**) consists of a hierarchically ordered set of edgenodes corresponding to c`omplete edges from the parser's chart. The "most probable" parse tree that is returned by the parser **14** (and which provides the basis for further processing) is constructed by extracting from the packed representation **25**, the information necessary to construct a treenode corresponding to the most probable edgenode at each node of the parse tree. The edge class is used by the parser for encoding the course of the parse; consequently, edge objects are relatively large and have complex behavior. Although encoding a parse tree by use of edge objects has no apparent impact on parser performance when it returns only one parse tree per input word graph, returning all possible parses in this manner may have an adverse impact on system performance. A solution to this problem is to use the C++ inheritance mechanism to split the data and behavior of the edge class into: (1) a base class ("treenode"), which contains only the data and behavior that is necessary to define and process parse trees returned by the parser, and (2) a derived class (treenode: edge), which contains all of the remaining data and behavior (required for constructing and maintaining the parses in the parser's agenda and chart objects). In the discussion that follows, the base class "treenode" will be referred to as a treenode, while the derived class "edge" will be referred to as an edgenode.

Referring to **FIG. 4**, the packed representation **25** consists of a subset of edgenodes corresponding to the (complete) edges in the parser's chart. Each edgenode **30** has associated with it a substitution list **32**, membership in which is shown in the packed representation schematic in **FIG. 4** by inclusion in a rectangle **32**, with ordering in the substitution list indicated by an arrow **31**

(e.g., edgenodes C0 (**32C0**) and C1 (**32C1**) are in the same substitution list **32**; note that the numeric indices are used for expository purposes only, as both edges **32C0** and **32C1** represent expansions of the nonterminal symbol "C," which can be seen by reference to the active ruleset **40** (upper right-hand corner of **FIG. 5**).

Substitution lists **32** have the following properties: (1) each edgenode in the list has the same label (i.e., all edgenodes were generated by clauses of the same BNF (Backus-Naur Form) rule, though they may correspond to different phrase-structure rules); (2) each edgenode in the list corresponds to an edge with the same starting and ending vertices in the parser's chart (though the paths connecting these vertices may be different); and (3) the edgenodes in the list are ordered according to score, with the "best" edgenode (according to the scoring metric) being the first element of the substitution list. Given these properties, a traversal of the packed representation **25** that expands the first edgenode in each substitution list will yield the tree that corresponds to the most probable parse (lower left-hand corner of **FIG. 5**), the terminals of which define the best path through the active word graph **28** (heavy line in **FIG. 8**). This algorithm is used to obtain the best parse whether or not the parser is running in multiple-parse mode, since it is possible (and, in fact, likely) that the parser **14** will obtain multiple structures over subspans of the word graph **28** that will be incorporated into the first successful parse **14** of the word graph **28** (note that, when run in single-parse mode, the substitution list of the topmost edgenode in the packed representation returned by the parser **14** is guaranteed to contain only one edgenode).

An unordered set of alternative parses can be obtained from a given packed representation **25** by an exhaustive traversal of the representation which incorporates the processing of the substitution lists as described below. If $\{E_n\}$ is the set of n edgenodes that define the most probable parse obtained from the packed representation, and $ki$ is the number of edgenodes in the substitution list corresponding to the edgenode $E_i$, then the number of parse

trees returned by the traversal will be less than or equal to $\prod_{i=1}^{n} k_i$. The number of parse trees may be less than this number due to dependencies resulting from the dominance relationships in the tree; (e.g. in the example shown in **FIG. 5**, there are only three parses (rather than four) because the substitution list containing edgenodes D0 and D1 is dominated by only one of the edgenodes in the substitution list containing edgenodes C0 and C1, not both of them).

As discussed above, the most probable parse for a given sentence is obtained from the packed representation **25** generated by the parser **14** (after it has parsed the sentence) by choosing the first element from each substitution list **32** during a traversal of the packed representation **25**. An ordered set of parses may therefore be obtained from the packed representation **25** by generalizing the traversal algorithm to operate on "forests" of trees as follows: (1) each time a substitution list **32** containing more than one edgenode (e.g., **32C0**, **32C1**) is encountered during the traversal, replicate the partial trees in the forest currently under construction as many times as there are edgenodes in the substitution list **32**; (2) update each copy of the forest with a treenode corresponding to a different edgenode from the substitution list **32**; and (3) continue the traversal through each copy of the forest according to the order of elements in the substitution list **32** (thus completing the processing of all of the edgenodes below a particular edgenode in the list before moving on to the next edgenode in the list). The unpacking module **20** is an object-oriented implementation based on this algorithm.

Note that this algorithm ensures only that all of the parse trees encoded in the packed representation **25** are obtained, not that they are ordered according to probability (although the best parse, as noted above, is guaranteed to be first). This is because the algorithm generates all of the subtrees corresponding to the expansion of a given edgenode in a substitution list **32** before it generates any of the subtrees corresponding to

the subsequent edgenodes in the substitution list **32**. In the example shown in **FIG. 5**, all of the subtrees containing a treenode labeled C0 will be generated before any of the subtrees that contain a treenode labeled C1. While there is strict ordering on the first subtree in each of these sets (i.e., the subtree containing the treenodes labeled C0 and D0 is more probable than the one containing the treenode labeled C1), such an ordering does not necessarily hold for any other pair of subtrees drawn from the sets (e.g., in the example, depending on the probabilities involved, the second-most-probable tree **37** containing treenodes C0 and D1 may be either more or less probable than the most probable tree containing treenode C1 (**38**). This requires that each new tree, after it has been generated by the algorithm presented above, must be merged into the list of completed trees (rather than added to its end) based on its probability, in order to ensure that the final list is ordered according to the trees' probability of occurrence.

Referring to **FIGS. 3B** and **3C**, a forest object is represented as a box with two compartments. The upper compartment of the box contains the label of the forest object and the lower compartment of the box contains a specification of the state of the forest object as follows. A "λ" in the lower compartment of the box specifies that the forest object is empty. A "U" in the lower compartment of the box indicates that the state of the forest object is unspecified (i.e., whether or not it is empty is irrelevant to the example.) If the forest object is neither empty nor in an unspecified state, then the lower compartment of the box is empty and the entire contents of the forest object is indicated by at least one arrow that connects it to at least one other forest object. If the number of forest objects contained in the set of connected forest objects is unspecified, the contents of the forest object are indicated by showing the first and last elements of the set, suitably indexed, with ellipses indicating the intervening forest objects in the set and ellipses indicating the arrows that connect these intervening forest objects to the containing forest object.

Referring to **FIG. 3B**, the self-embed operation on a forest object labeled Fx is defined as: (1) relabel Fx as Fx.0, (2) construct an empty forest

object labeled Fx, and (3) add Fx.0 to Fx. **FIG. 3B** presents a schematic of the self-embed operation showing the initial state (3B.0), the state after step 1 (3B.1), the state after step 2 (3B.2), and the state after step 3 (3B.3), which is the final state.

The N-fold replication operation on a forest object labeled Fx is defined as: (1) perform the self-embed operation on Fx; (2) construct N - 1 copies of Fx.0, labeled Fx.1 through Fx.(N-1); and (3) add Fx.1 through Fx.(N-1) to Fx. **FIG. 3C** presents a schematic of the N-fold replication operation showing the initial state (3C.0), the state after step 1 (3C.1), the state after step 2 (3C.2), and the state after step 3 (3C.3), which is the final state.

Two other operations on forest objects are defined as follows:

(1) The vector-update operation for a forest object Fx and a vector V of edgenodes is only possible if Fx is of cardinality N (i.e., it contains N embedded forests, labeled Fx.0 through Fx. (N-1)) and vector V is of length N. When this is true, the operation proceeds by creating a treenode Ti corresponding to the $i^{th}$ element of vector V and adding Ti to forest Fi (the $i^{th}$ forest object in Fx) under its active node, thus making it the new active node of Fx.i.

(2) The scalar-update operation for a forest object Fx and a treenode T is defined as: (1) construct N copies of T, where N is the cardinality of Fx, storing the copies in a set {T1,..., TN}, and (2) for each forest object Fx.i in Fx, add the treenode Ti to its active node. Note that adding a treenode to the active node of a forest that itself contains one or more forests has the effect of recursively adding this treenode to the active node of each of the embedded forests.

Referring to **FIG. 9**, the above algorithm can be implemented by use of the following four classes:

1 . The *Treenode* class **42** encodes a single node in a parse tree and can directly dominate an unspecified number of other Treenodes **42**. Each Treenode **42** contains an unbounded collection of Treenode pointers which reference its directly subordinate nodes **42a** and also includes a pointer to the Treenode **42** (if any) that directly dominates it **42b**. Additionally,

because of the synchronous construction behavior required by the Tree class, each Treenode **42** needs to "know" whether or not it is still under construction (i.e., whether it can still receive subordinate nodes). This requires special behavior by the Treenode copy constructor (which recursively performs a deep copy of all Treenodes dominated by the Treenode being copied), in order to ensure that this information is properly identified and transmitted.

2. The *Tree* class **44** encodes a single parse tree (which is either complete or "partial," i.e., under construction), consisting of one or more Treenode objects **42**. Pointers to two specific Treenode objects can be requested from a Tree object, its root (Tree root pointer **44a**), and its "active node" (Active Treenode pointer **44b**). The latter is NULL if the tree **44** is complete. If the tree **44** is partial, then the active node is the one that is modified during the course of tree completion. This encodes the restriction that a Tree object can only grow at one point during its construction (though, of course, this point will move around within the Tree). Because the Treenode copy constructor performs a recursive deep copy, the Tree copy constructor is accordingly simplified (i.e., to copying the root node and then ensuring that the active node information is properly transmitted).

3. The *Forest* class **46** contains either: (1) a single Tree object **46a** (which may be either partial or complete); or (2) an ordered set of one or more Forest objects **46b**. In the latter case, the Forest objects **46b** will be either all partial or all complete, thus a Forest object **46b** itself may be also said to be either partial or complete. If the Forest **46** is partial, then it has an "active nodeset," which consists of the set of all active nodes of its constituent objects (i.e., either Trees or Forests). This nodeset may be updated by either: (1) adding a single Treenode to it, with the result that the Treenode is cloned and added to all of the objects in the Forest (at their active nodes or nodesets, which are updated accordingly); or (2) adding a vector of Treenodes which is the same length as the number of Forests in the Forest (with the result that the vector elements are added in pairwise fashion to the active nodes of the Forests). This permits the simultaneous "growing" of the Tree objects in the Forest. Execution of the node-closure operation on the active nodeset results

in the new active node for each Tree in the Forest being determined by that Tree's geometry, with the Forest's nodeset updated accordingly. Finally, an *n*-fold replication operation may be applied to a given Forest object, resulting in a new Forest object that contains n identical copies of the original Forest object.

4. The *Edge* class **48** is the class used by the parser **14** to encode edge information during the course of the parse. The Edge class is composed of: (1) a proper subset of the data and functions of the Edge class currently used by the parser **14**, and (2) the static "LoadEdge" function used to interpret the commands of the declarative packed-edge specification language. Every Edge **48** contains zero or one Previous Edge pointers **48a**, zero or one Next Edge pointers **48b**, and zero or more back pointers **48c**. As shown in the UML diagram of **FIG. 9**, all interaction with this class is handled through the Forest class **46**; thus the integration of the functionality described above into the parser **14** is straightforwardly localized to a single interface. Edges and Treenodes may be implemented as separate classes. Alternatively, they may be linked by inheritance in order to streamline the implementation of the parser.

As discussed above, when the parser **14** is run in multiple-parse mode, the resulting parses are generated and stored in a packed representation **25**, a simplified example of which is shown in the upper left-hand corner of **FIG. 6**. The most probable parse **36** for a given sentence is obtained from the packed representation **25** by choosing the first element **32a** from each substitution list **32** during a traversal of the packed representation **25**. As also discussed above, an ordered set of parses may therefore be obtained from the packed representation **25** by generalizing the traversal algorithm to operate on "forests" of trees as follows:

During the traversal of the packed representation:

1. Each time the first edgenode in a substitution list **32** containing N elements, N > 1, is encountered, an N-fold replication of the current forest Fx is performed.

2. A vector update of Fx is then performed using the substitution list (which contains N elements).

3. The current forest pointer is set to point at the forest Fx.0 and the current node pointer is set to point at the next edgenode in the packed representation.

The traversal then continues through each forest Fx.i in Fx according to the order of elements in the substitution list **32** (thus completing the processing of all of the edgenodes below a particular edgenode in the list before the processing of the next edgenode in the list is begun).

The traversal of the packed representation therefore involves the updating of two pointers: (1) the current node pointer, which references the edgenode that is currently being processed in the packed representation, and (2) the current forest pointer, which references the forest object currently being modified. As discussed above, a forest object is modified by either adding a given treenode to the "active node" of the forest object or by applying the "node closure" operation to the forest's active node (which, depending on the internal structure of the forest, will result in either a new active node being activated in the forest or in the forest becoming complete; i.e., containing no active node). In the initial state of the unpacking algorithm, the current node pointer points at the root edgenode in the packed representation and the current forest pointer points at an empty forest object labeled F0.

Referring to **FIGS. 2** and **3A** an example of a preferred embodiment of the unpacking process is illustrated. From the packed representation input (block 49) the root edgenode **30A** (**FIG. 4**) of the packed representation **25** is obtained and becomes the current edgenode (block 50). An empty forest object labeled F0 is created and becomes the current forest (block 51). Because the current edgenode **30A** is the first edgenode in the substitution list **32A** (block 52), N is set to the length of the substitution list for the current edgenode (block 53). For edgenode **30A**, the length of the substitution list **32A** is equal to 1. Because N is not greater than 1 (block 54) a scalar update of the current forest F0 is performed with the current edgenode (block 55),

resulting in a treenode labeled A being added to the (empty) current forest F0, where it becomes the active node.

The next edgenode is now obtained (block 59) starting at block 64 as shown in **FIG. 3A**. Because the current edgenode **30A** has at least one child (block 66), the next edgenode is set to the leftmost child of the current edgenode (block 68), that is, to edgenode **30B**. Because the next edgenode is not NULL (block 60), the current edgenode is set to the next edgenode **30B** (block 61).

Next, because the current edgenode **30B** is the first edgenode in its substitution list **32B** (block 52), N is set to the length of the substitution list for the current edgenode (block 53). For edgenode **30B**, the length of the substitution list **32B** is equal to 1. Because N is not greater than 1 (block 54) a scalar update of the current forest F0 is performed with the current edgenode (block 55), resulting in a treenode labeled B being added to the current forest F0, under its active node (the treenode labeled A). Because the edgenode **30B** is a nonterminal node, its corresponding treenode labeled B is also a nonterminal node, thus the nonterminal treenode labeled B becomes the new active node in the current forest F0.

The next edgenode is now obtained (block 59) as shown in **FIG. 3A**. Because the current edgenode **30B** has at least one child (block 66), the next edgenode is set to the leftmost child of the current edgenode (block 68), that is, to edgenode **30W0**. Because the next edgenode is not NULL (block 60), the current edgenode is set to the next edgenode **30W0** (block 61).

Next, because the current edgenode **30W0** is the first edgenode in its substitution list **32W0** (block 52), N is set to the length of the substitution list for the current edgenode (block 53). For edgenode **30W0**, the length of the substitution list **32W0** is equal to 1. Because N is not greater than 1 (block 54) a scalar update of the current forest F0 is performed with the current edgenode (block 55), resulting in a treenode labeled w0 being added to the current forest F0, under its active node (the treenode labeled B). Because the edgenode **30W0** is a terminal node, its corresponding treenode

labeled w0 is also a terminal node, thus the treenode labeled B remains the active node in the current forest F0.

The next edgenode is now obtained (block 59) as shown in **FIG. 3A**. Because the current edgenode **30W0** does not have at least one child (block 66), it is tested to see if it is the last edgenode in the substitution list **32W0** (block 70). Because it is the only edgenode in the substitution list **32W0**, it is necessarily the last one, so it is tested to see if it has a sibling to its immediate right (block 76). Because it does not have a sibling to its immediate right, the node closure operation is applied to the current forest F0. The active node of the current forest F0 is the treenode labeled B. Thus the application of the node closure operation results in the treenode labeled A (which is the parent node of the treenode labeled B) becoming the new active node of the current forest F0 (block 77). The current edgenode is then tested to see if it has a parent (block 82). Because the current edgenode **30W0** has a parent (edgenode **30B**), the current edgenode becomes edgenode **30B** (block 86). Because the current forest is F0, it remains unchanged (block 87).

The new current edgenode **30B** is now tested to see if it is the last edgenode in the substitution list **32B** (block 70). Because it is the only edgenode in the substitution list, it is necessarily the last one, so it is tested to see if it has a sibling to its immediate right (block 76). Because it has a sibling to its immediate right, the next edgenode is set to this sibling, that is, to edgenode **30C0** (block 78). Because the next edgenode is not NULL (block 60), the current edgenode is set to the next edgenode **30C0** (block 61).

Next, because the current edgenode **30C0** is the first edgenode in its substitution list **32C** (block 52), N is set to the length of the substitution list for the current edgenode (block 53). For edgenode **30C0**, the length of the substitution list **32C** is equal to 2. Because N is greater than 1 (block 54) an N-fold replication of the current forest F0 is performed (with N equal to 2). Referring to **FIG. 6**, this replication results in the partial tree **90A** in the current forest F0 being copied into two new forests **91** and **92**, respectively labeled F0.0 and F0.1, which become the new contents of the current forest F0. Next, a vector update of the current forest F0 is performed with the substitution list

**32C** of the current edgenode **30C0**. This results in a treenode labeled C0 (from the first element of the substitution list **32C**) being added under the active node (the treenode labeled A) of forest F0.0 (thus becoming the new active node of this forest), and a treenode labeled C1 (from the second element of the substitution list **32C**) being added under the active node (the treenode labeled A) of forest F0.1 (thus becoming the new active node of this forest), as shown in the box labeled "First Replication" in the upper right-hand corner of **FIG. 6**. The current forest is now set to the first forest in F0 (90), that is, to forest F0.0 (91) (block 58).

The next edgenode is now obtained (block 59) as shown in **FIG. 3A**. Because the current edgenode **30C** has at least one child (block 66), the next edgenode is set to the leftmost child of the current edgenode (block 68), that is, to edgenode **30D0**. Because the next edgenode is not NULL (block 60), the current edgenode is set to the next edgenode **30D0** (block 61).

Next, because the current edgenode **30D0** is the first edgenode in its substitution list **32D** (block 52), N is set to the length of the substitution list for the current edgenode (block 53). For edgenode **30D0**, the length of the substitution list **32D** is equal to 2. Because N is greater than 1 (block 54) an N-fold replication (94) of the current forest F0.0 is performed (with N equal to 2). This replication results in the partial tree in the current forest F0.0 (91) being copied into two new forests, respectively labeled F0.0.0 (95) and F0.0.1 (96), which become the new contents of the current forest F0.0 (91). Next, a vector update of the current forest F0.0 (91) is performed with the substitution list **32D** of the current edgenode **30D0**. This results in a treenode labeled D0 (from the first element of the substitution list **32D**) being added under the active node (the treenode labeled C0) of forest F0.0.0 (thus becoming the new active node of this forest) and a treenode labeled D1 (from the second element of the substitution list **32D**) being added under the active node (the treenode labeled C0) of forest F0.0.1 (thus becoming the new active node of this forest), as shown in the box 94 labeled "Second Replication" in the left central portion of **FIG. 6**. The current forest is now set to the first forest in F0.0, that is, to forest F0.0.0 (95) (block 58).

The next edgenode is now obtained (block 59) as shown in **FIG. 3A**. Because the current edgenode **30D0** has at least one child (block 66), the next edgenode is set to the leftmost child of the current edgenode (block 68), that is, to edgenode **3OW2**. Because the next edgenode is not NULL (block 60), the current edgenode is set to the next edgenode **30W2** (block 61).

Next, because the current edgenode **3OW2** is the first edgenode in its substitution list **32W2** (block 52), N is set to the length of the substitution list for the current edgenode (block 53). For edgenode **30W2**, the length of the substitution list **32W2** is equal to 1. Because N is not greater than 1 (block 54) a scalar update of the current forest F0.0.0 is performed with the current edgenode (block 55), resulting in a treenode labeled w2 being added to the current forest F0.0.0, under its active node (the treenode labeled D0). Because the edgenode **30W2** is a terminal node, its corresponding treenode labeled w2 is also a terminal node, thus the treenode labeled D0 remains the active node in the current forest F0.0.0 (95).

The next edgenode is now obtained (block 59) as shown in **FIG. 3A**. Because the current edgenode **30W2** does not have at least one child (block 66), it is tested to see if it is the last edgenode in the substitution list **32W2** (block 70). Because it is the only edgenode in the substitution list **32W2**, it is necessarily the last one, so it is tested to see if it has a sibling to its immediate right (block 76). Because it has a sibling to its immediate right, the next edgenode is set to this sibling, that is, to edgenode **30W3** (block 78). Because the next edgenode is not NULL (block 60), the current edgenode is set to the next edgenode **30W3** (block 61).

Next, because the current edgenode **30W3** is the first edgenode in its substitution list **32W3** (block 52), N is set to the length of the substitution list for the current edgenode (block 53). For edgenode **30W3**, the length of the substitution list **32W3** is equal to 1. Because N is not greater than 1 (block 54) a scalar update of the current forest F0.0.0 (95) is performed with the current edgenode (block 55), resulting in a treenode labeled w3 being added to the current forest F0.0.0 under its active node (the treenode labeled D0). Because the edgenode **30W3** is a terminal node, its corresponding treenode

labeled w3 is also a terminal node, thus the treenode labeled D0 remains the active node in the current forest F0.0.0.

The next edgenode is now obtained (block 59) as shown in **FIG. 3A**. Because the current edgenode **30W3** does not have at least one child (block 66), it is tested to see if it is the last edgenode in the substitution list **32W3** (block 70). Because it is the only edgenode in the substitution list **32W3**, it is necessarily the last one, so it is tested to see if it has a sibling to its immediate right (block 76). Because it does not have a sibling to its immediate right, the node closure operation is applied to the current forest F0.0.0. The active node of the current forest F0.0.0 is the treenode labeled D0. Thus the application of the node closure operation results in the treenode labeled C0 (which is the parent node of the treenode labeled D0) becoming the new active node of the current forest F0.0.0 (block 77). The current edgenode is then tested to see if it has a parent (block 82). Because the current edgenode **30W3** has a parent (edgenode **30D0**), the current edgenode becomes edgenode **30D0** (block 86). Because the current forest is F0.0.0, not F0 (block 87), it is changed to the forest of the parent of the current edgenode (block 88), that is, to F0.0.

The new current edgenode **30D0** is now tested to see if it is the last edgenode in the substitution list **32D** (block 70). Because it is not the last edgenode in the substitution list **32D**, the next edgenode is set to the next edgenode in the substitution list **32D** (block 72), that is, to edgenode **30D1**. The current forest is now set to the forest of edgenode **30D1**, that is, to the forest labeled F0.0.1 (block 74). Because the next edgenode is not NULL (block 60), the current edgenode is set to the next edgenode **30D1** (block 61).

Because the current edgenode **30D1** is not the first edgenode in the substitution list **32D** (block 52), the next edgenode is now obtained (block 59) as shown in **FIG. 3A**. Because the current edgenode **30D1** has at least one child (block 66), the next edgenode is set to the leftmost child of the current edgenode (block 68), that is, to edgenode **30W1**. Because the next edgenode is not NULL (block 60), the current edgenode is set to the next edgenode **30W1** (block 61).

Next, because the current edgenode **30W1** is the first edgenode in its substitution list **32W1** (block 52), N is set to the length of the substitution list for the current edgenode (block 53). For edgenode **30W1**, the length of the substitution list **32W1** is equal to 1. Because N is not greater than 1 (block 54) a scalar update of the current forest F0.0.1 is performed with the current edgenode (block 55), resulting in a treenode labeled w1 being added to the current forest F0.0.1, under its active node (the treenode labeled D1). Because the edgenode **30W1** is a terminal node, its corresponding treenode labeled w1 is also a terminal node, thus the treenode labeled D1 remains the active node in the current forest F0.0.1.

The next edgenode is now obtained (block 59) as shown in **FIG. 3A**. Because the current edgenode **30W1** does not have at least one child (block 66), it is tested to see if it is the last edgenode in the substitution list **32W1** (block 70). Because it is the only edgenode in the substitution list **32W1**, it is necessarily the last one, so it is tested to see if it has a sibling to its immediate right (block 76). Because it does not have a sibling to its immediate right, the node closure operation is applied to the current forest F0.0.1. The active node of the current forest F0.0.1 is the treenode labeled D1. Thus the application of the node closure operation results in the treenode labeled C0 (which is the parent node of the treenode labeled D1) becoming the new active node of the current forest F0.0.1 (block 77). The current edgenode is then tested to see if it has a parent (block 82). Because the current edgenode **30W1** has a parent (edgenode **30D1**), the current edgenode becomes edgenode **30D1** (block 86). Because the current forest is F0.0.1, not F0 (block 87), it is changed to the forest of the parent of the current edgenode (block 88), that is, to F0.0.

The new current edgenode **30D1** is now tested to see if it is the last edgenode in the substitution list **32D** (block 70). Because it is the last edgenode in the substitution list **32D**, it is tested to see if it has a sibling to its immediate right (block 76). Because it has a sibling to its immediate right, the next edgenode is set to this sibling, that is, to edgenode **30W4** (block 78).

Because the next edgenode is not NULL (block 60), the current edgenode is set to the next edgenode **30W4** (block 61).

Next, because the current edgenode **30W4** is the first edgenode in its substitution list **32W4** (block 52), N is set to the length of the substitution list for the current edgenode (block 53). For edgenode **30W4**, the length of the substitution list **32W4** is equal to 1. Because N is not greater than 1 (block 54) a scalar update of the current forest F0.0 is performed with the current edgenode (block 55), resulting in a treenode labeled w4 being added to the current forest F0.0. Because the current forest F0.0 contains the two forests F0.0.0 and F0.0.1, each of these forests is updated at its active node with a copy of the treenode labeled w4 (in both of these forests, the current active node is the treenode labeled C0). Because the edgenode **30W4** is a terminal node, its corresponding treenode labeled w4 is also a terminal node, thus the active nodes of the forests in the current forest F0.0 are not changed.

The next edgenode is now obtained (block 59) as shown in **FIG. 3A**. Because the current edgenode **30W4** does not have at least one child (block 66), it is tested to see if it is the last edgenode in the substitution list **32W4** (block 70). Because it is the only edgenode in the substitution list **32W4**, it is necessarily the last one, so it is tested to see if it has a sibling to its immediate right (block 76). Because it has a sibling to its immediate right, the next edgenode is set to this sibling, that is, to edgenode **30W5** (block 78). Because the next edgenode is not NULL (block 60), the current edgenode is set to the next edgenode **30W5** (block 61).

Next, because the current edgenode **30W5** is the first edgenode in its substitution list **32W5** (block 52), N is set to the length of the substitution list for the current edgenode (block 53). For edgenode **30W5**, the length of the substitution list **32W5** is equal to 1. Because N is not greater than 1 (block 54) a scalar update of the current forest F0.0 is performed with the current edgenode (block 55), resulting in a treenode labeled w5 being added to the current forest F0.0. Because the current forest F0.0 contains the two forests F0.0.0 and F0.0.1, each of these forests is updated at its active node with a copy of the treenode labeled w5 (in both of these forests, the current

active node is the treenode labeled C0). Because the edgenode **30W5** is a terminal node, its corresponding treenode labeled w5 is also a terminal node, thus the active nodes of the forests in the current forest F0.0 are not changed.

The next edgenode is now obtained (block 59) as shown in **FIG. 3A**. Because the current edgenode **30W5** does not have at least one child (block 66), it is tested to see if it is the last edgenode in the substitution list **32W5** (block 70). Because it is the only edgenode in the substitution list **32W5**, it is necessarily the last one, so it is tested to see if it has a sibling to its immediate right (block 76). Because it does not have a sibling to its immediate right, the node closure operation is applied to the current forest F0.0 (block 77). Because the current forest F0.0 contains the two forests F0.0.0 and F0.0.1, the application of the node closure operation to it results in the node closure operation being applied to each of these forests in turn. The active node of the forest F0.0.0 is the treenode labeled C0. Thus the application of the node closure operation to the forest F0.0.0 results in the treenode labeled A (which is the parent node of the treenode labeled C0) becoming the new active node of the forest F0.0.0. Similarly, the active node of the forest F0.0.1 is the treenode labeled C0. Thus the application of the node closure operation to the forest F0.0.1 results in the treenode labeled A (which is the parent node of the treenode labeled C0) becoming the new active node of the forest F0.0.1.

Because it does not have a sibling to its immediate right, the node closure operation is applied to the current forest F0.0, resulting in the parent treenode (labeled C0) of the treenode labeled w3 becoming the new active node of the current forest F0.0 (block 77). The current edgenode is then tested to see if it has a parent (block 82). Because the current edgenode **30W5** has a parent (edgenode **30C0**), the current edgenode becomes edgenode **30C0** (block 86). Because the current forest is F0.0, not F0 (block 87), it is changed to the forest of the parent of the current edgenode (block 88), that is, to F0.

The new current edgenode **30C0** is now tested to see if it is the last edgenode in the substitution list **32C** (block 70). Because it is not the last

edgenode in the substitution list **32C**, the next edgenode is set to the next edgenode in the substitution list **32C** (block 72), that is, to edgenode **30C1**. The current forest is now set to the forest of edgenode **30C1**, that is, to the forest labeled F0.1 (block 74). Because the next edgenode is not NULL (block 60), the current edgenode is set to the next edgenode **30C1** (block 61).

Because the current edgenode is not the first edgenode in the substitution list (block 52), the next edgenode is now obtained (block 59) as shown in **FIG. 3A**. Because the current edgenode **30C1** has at least one child (block 66), the next edgenode is set to the leftmost child of the current edgenode (block 68), that is, to edgenode **30W2**. Because the next edgenode is not NULL (block 60), the current edgenode is set to the next edgenode **30W2** (block 61).

Next, because the current edgenode **30W2** is the first edgenode in its substitution list **32W2** (block 52), N is set to the length of the substitution list for the current edgenode (block 53). For edgenode **30W2**, the length of the substitution list **32W2** is equal to 1. Because N is not greater than 1 (block 54) a scalar update of the current forest F0.1 is performed with the current edgenode (block 55), resulting in a treenode labeled w2 being added to the current forest F0.1, under its active node (the treenode labeled C1). Because the edgenode **30W2** is a terminal node, its corresponding treenode labeled w2 is also a terminal node, thus the treenode labeled C1 remains the active node in the current forest F0.1.

The next edgenode is now obtained (block 59) as shown in **FIG. 3A**. Because the current edgenode **30W2** does not have at least one child (block 66), it is tested to see if it is the last edgenode in the substitution list **32W2** (block 70). Because it is the only edgenode in the substitution list **32W2**, it is necessarily the last one, so it is tested to see if it has a sibling to its immediate right (block 76). Because it has a sibling to its immediate right, the next edgenode is set to this sibling, that is, to edgenode **30W3** (block 78). Because the next edgenode is not NULL (block 60), the current edgenode is set to the next edgenode **30W3** (block 61).

Next, because the current edgenode **30W3** is the first edgenode in its substitution list **32W3** (block 52), N is set to the length of the substitution list for the current edgenode (block 53). For edgenode **30W3**, the length of the substitution list **32W3** is equal to 1. Because N is not greater than 1 (block 54) a scalar update of the current forest F0.1 is performed with the current edgenode (block 55), resulting in a treenode labeled w3 being added to the current forest F0.1, under its active node (the treenode labeled C1). Because the edgenode **30W3** is a terminal node, its corresponding treenode labeled w3 is also a terminal node, thus the treenode labeled C1 remains the active node in the current forest F0.1.

The next edgenode is now obtained (block 59) as shown in **FIG. 3A**. Because the current edgenode **30W3** does not have at least one child (block 66), it is tested to see if it is the last edgenode in the substitution list **32W3** (block 70). Because it is the only edgenode in the substitution list **32W3**, it is necessarily the last one, so it is tested to see if it has a sibling to its immediate right (block 76). Because it has a sibling to its immediate right, the next edgenode is set to this sibling, that is, to edgenode **30E** (block 78). Because the next edgenode is not NULL (block 60), the current edgenode is set to the next edgenode **30E** (block 61).

Next, because the current edgenode **30E** is the first edgenode in its substitution list **32E** (block 52), N is set to the length of the substitution list for the current edgenode (block 53). For edgenode **30E**, the length of the substitution list **32E** is equal to 1. Because N is not greater than 1 (block 54) a scalar update of the current forest F0.1 is performed with the current edgenode (block 55), resulting in a treenode labeled E being added to the current forest F0.1, under its active node (the treenode labeled C1). Because the edgenode **30E** is a nonterminal node, its corresponding treenode labeled E is also a nonterminal node, thus the nonterminal treenode labeled E becomes the new active node in the current forest F0.1.

The next edgenode is then obtained (block 59) as shown in **FIG. 3A**. Because the current edgenode **30E** has at least one child (block 66), the next edgenode is set to the leftmost child of the current edgenode (block 68), that

is, to edgenode **30W4**. Because the next edgenode is not NULL (block 60), the current edgenode is set to the next edgenode **30W4** (block 61).

Next, because the current edgenode **30W4** is the first edgenode in its substitution list **32W4** (block 52), N is set to the length of the substitution list for the current edgenode (block 53). For edgenode **30W4**, the length of the substitution list **32W4** is equal to 1. Because N is not greater than 1 (block 54) a scalar update of the current forest F0.1 is performed with the current edgenode (block 55), resulting in a treenode labeled w4 being added to the current forest F0.1, under its active node (the treenode labeled E). Because the edgenode **30W4** is a terminal node, its corresponding treenode labeled w4 is also a terminal node, thus the treenode labeled E remains the active node in the current forest F0.1.

The next edgenode is now obtained (block 59) as shown in **FIG. 3A**. Because the current edgenode **30W4** does not have at least one child (block 66), it is tested to see if it is the last edgenode in the substitution list **32W4** (block 70). Because it is the only edgenode in the substitution list **32W4**, it is necessarily the last one, so it is tested to see if it has a sibling to its immediate right (block 76). Because it has a sibling to its immediate right, the next edgenode is set to this sibling, that is, to edgenode **30W6** (block 78). Because the next edgenode is not NULL (block 60), the current edgenode is set to the next edgenode **30W6** (block 61).

Next, because the current edgenode **30W6** is the first edgenode in its substitution list **32W6** (block 52), N is set to the length of the substitution list for the current edgenode (block 53). For edgenode **30W6**, the length of the substitution list **32W6** is equal to 1. Because N is not greater than 1 (block 54) a scalar update of the current forest F0.1 is performed with the current edgenode (block 55), resulting in a treenode labeled w6 being added to the current forest F0.1, under its active node (the treenode labeled E). Because the edgenode **30W6** is a terminal node, its corresponding treenode labeled w6 is also a terminal node, thus the treenode labeled E remains the active node in the current forest F0.1.

The next edgenode is now obtained (block 59) as shown in **FIG. 3A**. Because the current edgenode **30W6** does not have at least one child (block 66), it is tested to see if it is the last edgenode in the substitution list **32W6** (block 70). Because it is the only edgenode in the substitution list **32W6** should be inserted as shown, it is necessarily the last one, so it is tested to see if it has a sibling to its immediate right (block 76). Because it does not have a sibling to its immediate right, the node closure operation is applied to the current forest F0.1, resulting in the parent treenode of the treenode labeled E (i.e., the treenode labeled C1) becoming the new active node of the current forest F0.1 (block 77). The current edgenode is then tested to see if it has a parent (block 82). Because the current edgenode **30W6** has a parent (edgenode **30E**), the current edgenode becomes edgenode **30E** (block 86). Because the current forest is F0.1, not F0 (block 87), it is changed to the forest of the parent of the current edgenode (block 88), that is, to F0.1 (thus remaining unchanged).

The new current edgenode **30E** is now tested to see if it is the last edgenode in the substitution list **32E** (block 70). Because it is the only edgenode in the substitution list **32E**, it is necessarily the last one, so it is tested to see if it has a sibling to its immediate right (block 76). Because it does not have a sibling to its immediate right, the node closure operation is applied to the current forest F0.1, resulting in the parent treenode of the treenode labeled C1 (i.e., the treenode labeled A) becoming the new active node of the current forest F0.1 (block 77). The current edgenode is then tested to see if it has a parent (block 82). Because the current edgenode **30E** has a parent (edgenode **30C1**), the current edgenode becomes edgenode **30C1** (block 86). Because the current forest is F0.1, not F0 (block 87), it is changed to the forest of the parent of the current edgenode (block 88), that is, to F0.

The new current edgenode **30C1** is now tested to see if it is the last edgenode in the substitution list **32C** (block 70). Because it is the last edgenode in the substitution list **32C**, it is tested to see if it has a sibling to its immediate right (block 76). Because it does not have a sibling to its

immediate right, the node closure operation is applied to the current forest F0. Because the forest F0 contains the forests F0.1 and F0.0 (and the forest F0.0 itself contains the forests F0.0.0 and F0.0.1), the node closure operation is applied to each of these contained forests. Since the active node in forest F0.1 is the treenode labeled C1, it is closed and the new active node in this forest becomes the treenode labeled A. Similarly, since the active node in forest F0.0.0 is the treenode labeled C0, it is closed and the new active node in this forest becomes the treenode labeled A. Finally, since the active node in forest F0.0.1 is the treenode labeled C0, it is closed and the new active node in this forest becomes the treenode labeled A. The current edgenode is then tested to see if it has a parent (block 82). Because the current edgenode **30C1** has a parent (edgenode **30A**), the current edgenode becomes edgenode **30A** (block 86). Because the current forest is F0 (block 87) it remains unchanged.

The new current edgenode **30A** is now tested to see if it is the last edgenode in the substitution list **32A** (block 70). Because it is the only edgenode in the substitution list **32A**, it is necessarily the last one, so it is tested to see if it has a sibling to its immediate right (block 76). Because it does not have a sibling to its immediate right, the node closure operation is applied to the current forest F0. Because the forest F0 contains the forests F0.1 and F0.0 (and the forest F0.0 itself contains the forests F0.0.0 and F0.0.1), the node closure operation is applied to each of these contained forests. Since the active node in each of these forests is the treenode labeled A (which is the root treenode of each forest), this results in each forest being completed. Because the current edgenode **30A** is the root edgenode of the packed representation, it does not have a parent, so the next edgenode is set to NULL (block 84).

Because the next edgenode is NULL (block 60), the unpacking module is finished processing (block 62).

Referring to **FIG. 7**, the unpacked forest **110** contains each of the three parses, including the most probable parse (36), alternative parse 1 (37) and

alternative parse 2 (38). The parse trees in the unpacked forest object **22** are readable by conventional semantic interpreters.

As discussed above, although the most probable parse is guaranteed to be the first one returned by this algorithm, the relative order of the remaining parses must be determined by reference to their relative weights. This is accomplished by merging the parse trees contained in a particular Forest object into a frequency-sorted list that can be returned by a Forest-class accessor. This list is a static data member of the Forest class, into which a pointer to each Tree is inserted upon Tree completion (thus obviating the need for an additional traversal of the Forest to obtain these pointers).

While the embodiments of the invention disclosed herein are presently considered to be preferred, various changes and modifications can be made without departing from the spirit and scope of the invention. The scope of the invention is indicated in the appended claims, and all changes that come within the meaning and range of equivalents are intended to be embraced therein.

WE CLAIM:

1. A method of decoding a packed representation of multiple parses comprising the steps of:

providing a packed representation including at least one edgenode, each edgenode including a substitution list;

creating a current forest object;

replicating the current forest object for each edgenode having a substitution list containing greater than one edgenode; and

traversing each edgenode of the packed representation.

2. The method of claim 1 further comprising the step of performing a scalar update of the current forest object for each edgenode having a substitution list containing exactly one edgenode.

3. The method of claim 1 further comprising the step of traversing each edgenode of the packed representation using a depth-first traversal.

4. The method of claim 1 wherein the current forest object is replicated by a number equal to a number of edgenodes in the substitution list of a current edgenode when the number of edgenodes in the substitution list is greater than one.

5. The method of claim 4 further comprising the step of performing a vector update of the current forest object with the substitution list of the current edgenode.

6. The method of claim 4 further comprising the step of updating each of the replicated forest objects with an element corresponding to a different edgenode in the substitution list.

7. The method of claim 1 further comprising the step of setting a current edgenode to a root edgenode of the packed representation.

8. The method of claim 7 further comprising the step of setting the current forest object to an empty forest object.

9. The method of claim 8 further comprising the step of setting a next edgenode of the packed representation to a leftmost child of the current edgenode.

10. A program for decoding a packed representation of parses stored on computer readable medium comprising the steps of:

computer readable program code for creating a current forest object;

computer readable program code for traversing each edgenode of the packed representation; and

computer readable program code for replicating the forest object for each edgenode having a substitution list of elements greater than 1.

11. The program of claim 10 wherein the forest object is replicated a number of times equal to the number of elements in the substitution list.

12. The program of claim 11 further comprising computer readable code for performing a scalar update of the current forest object for each edgenode having a substitution list containing exactly one edgenode.

13. The program of claim 10 further comprising computer readable code for updating each of the replicated forests with a treenode corresponding to one of the elements in the substitution list.

14. The program of claim 10 further comprising computer readable code for setting a current edgenode to a root edgenode of the packed representation, and for setting the current forest object to an empty forest object.

15. The program of claim 14 further comprising:

computer readable program for setting a next edgenode to a leftmost child of the current edgenode; and

setting the current edgenode to the next edgenode.

16. The program of claim 15 further comprising

computer readable program code for setting the next edgenode to a next one of the edgenodes in the substitution list when the current edgenode does not have at least one child.

17. The program of claim 16 further comprising

computer readable program code for setting the current forest object to a forest object of the next one of the edgenodes in the substitution list.

18. The program of claim 17 further comprising computer readable program code for performing a node closure operation on a current forest object when the current edgenode in the last edgenode in the substitution list and when the current edgenode does not have a sibling to the right of the current edgenode.

19. The computer program of claim 18 further comprising computer readable program code for setting a next edgenode to null after the node closure operation, when the current edgenode does not have a parent.

20. The computer program of claim 18 further comprising computer readable program code for setting the current edgenode to parent of current edgenode, after the closure operation.

21. A system for decoding multiple parses comprising:

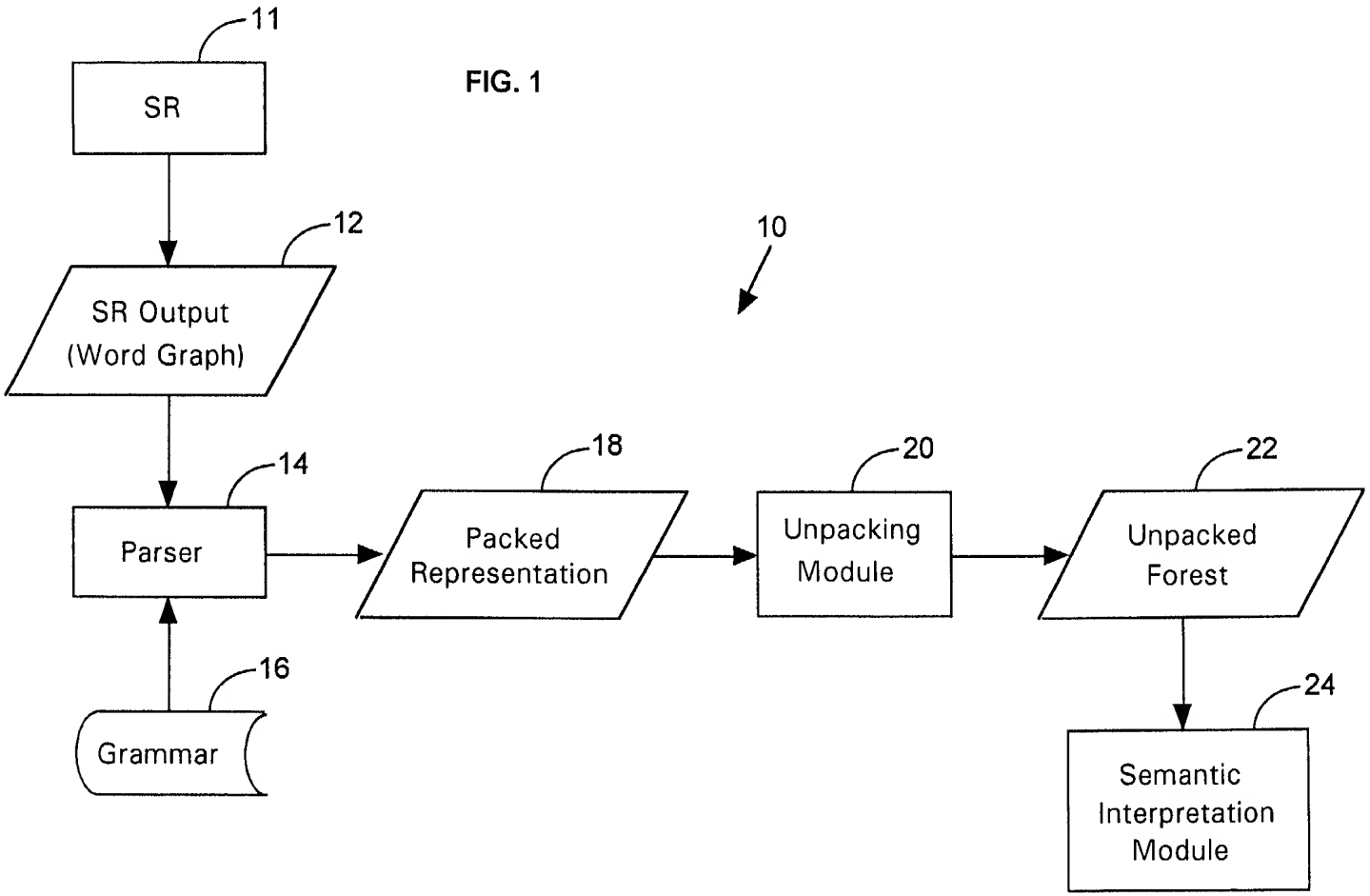
a parser which receives output from a speech recognizer and creating parses stored in a packed representation, the packed representation including a plurality of edgenodes; each edgenode including a substitution list;

an unpacking program stored on a computer readable medium including program code for creating an unpacked forest including the steps of creating a current forest object, traversing each edgenode of the packed representation using a depth-first traversal, replicating the current forest object a number of times equal to the number of edgenodes in the substitution list, and updating each copy of the current forest object with a treenode corresponding to one of the edgenodes of the substitution list.

## ABSTRACT OF THE DISCLOSURE

A program, system and method for decoding a packed representation of multiple parses creates an unpacked forest to be read by a semantic interpretation module from a packed representation is provided. The packed representation includes at least one edgenode and each edgenode includes a substitution list. A current forest object is created and is replicated for each edgenode having a substitution list containing greater than one edgenode. Each of the copies of the current forest object are updated with one of the edgenodes from the substitution list. Each edgenode of the packed representation is traversed using a depth-first traversal.

FIG. 1


11
SR
12
SR Output
(Word Graph)
10
14
Parser
16
Grammar
18
Packed
Representation
20
Unpacking
Module
22
Unpacked
Forest
24
Semantic
Interpretation
Module

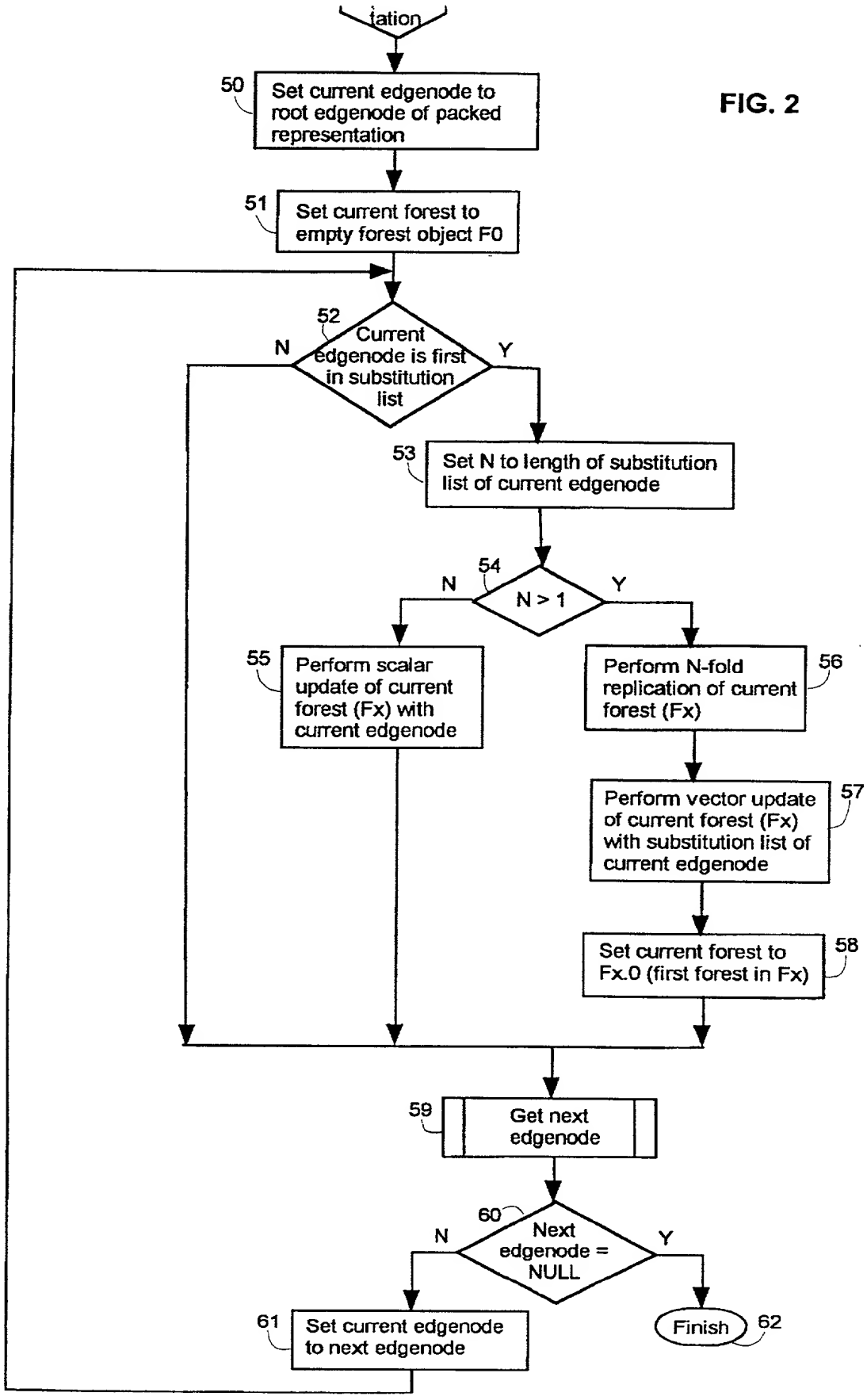

tation
50
Set current edgenode to root edgenode of packed representation
51
Set current forest to empty forest object F0
52
Current edgenode is first in substitution list
N
Y
53
Set N to length of substitution list of current edgenode
54
N > 1
N
Y
55
Perform scalar update of current forest (Fx) with current edgenode
56
Perform N-fold replication of current forest (Fx)
57
Perform vector update of current forest (Fx) with substitution list of current edgenode
58
Set current forest to Fx.0 (first forest in Fx)
59
Get next edgenode
60
Next edgenode = NULL
N
Y
61
Set current edgenode to next edgenode
Finish
62

FIG. 2

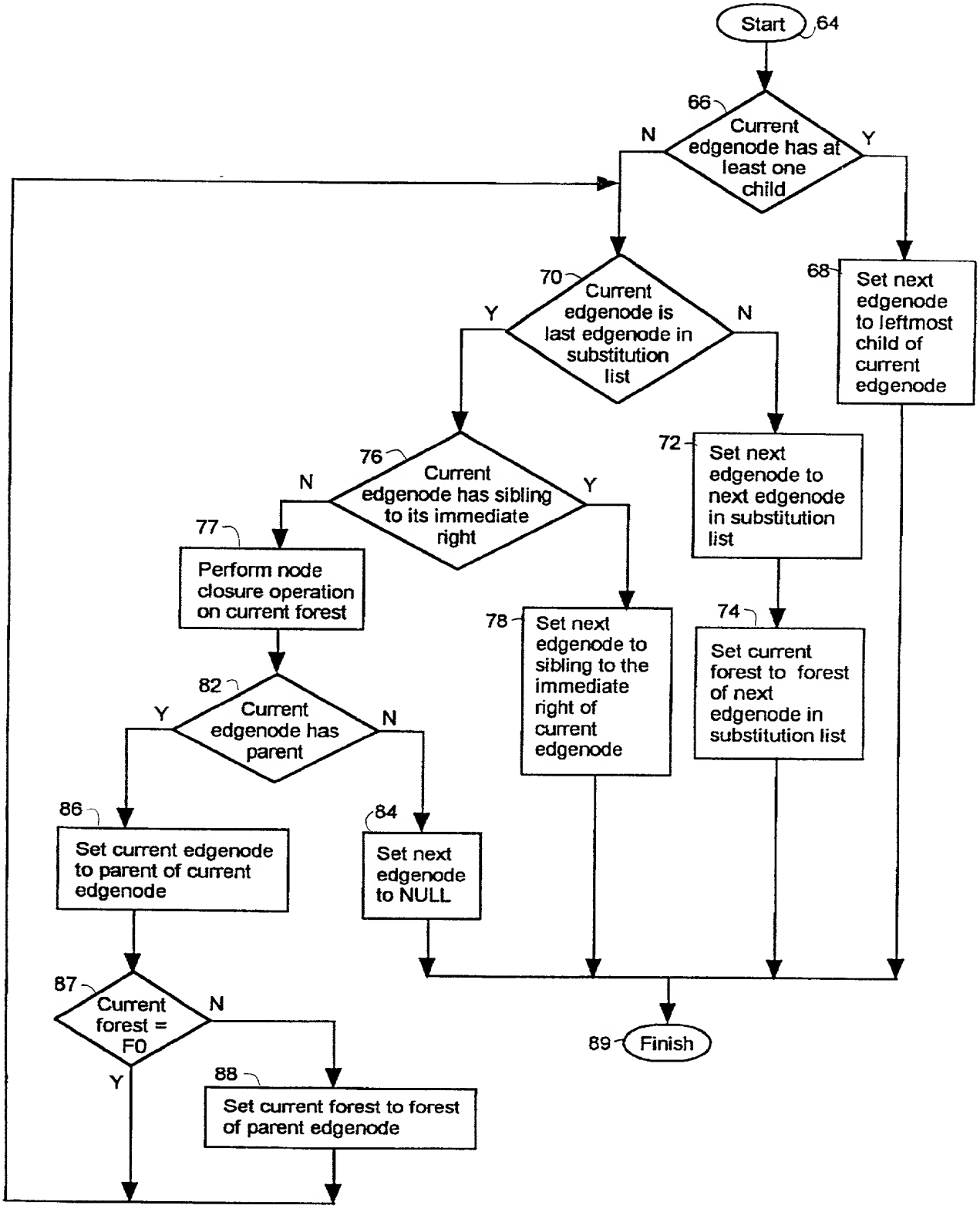

Start
64
66
Current edgenode has at least one child
N
Y
68
Set next edgenode to leftmost child of current edgenode
70
Current edgenode is last edgenode in substitution list
Y
N
72
Set next edgenode to next edgenode in substitution list
74
Set current forest to forest of next edgenode in substitution list
76
Current edgenode has sibling to its immediate right
N
Y
77
Perform node closure operation on current forest
78
Set next edgenode to sibling to the immediate right of current edgenode
82
Current edgenode has parent
Y
N
86
Set current edgenode to parent of current edgenode
84
Set next edgenode to NULL
87
Current forest = F0
N
Y
88
Set current forest to forest of parent edgenode
89
Finish

FIG. 3A

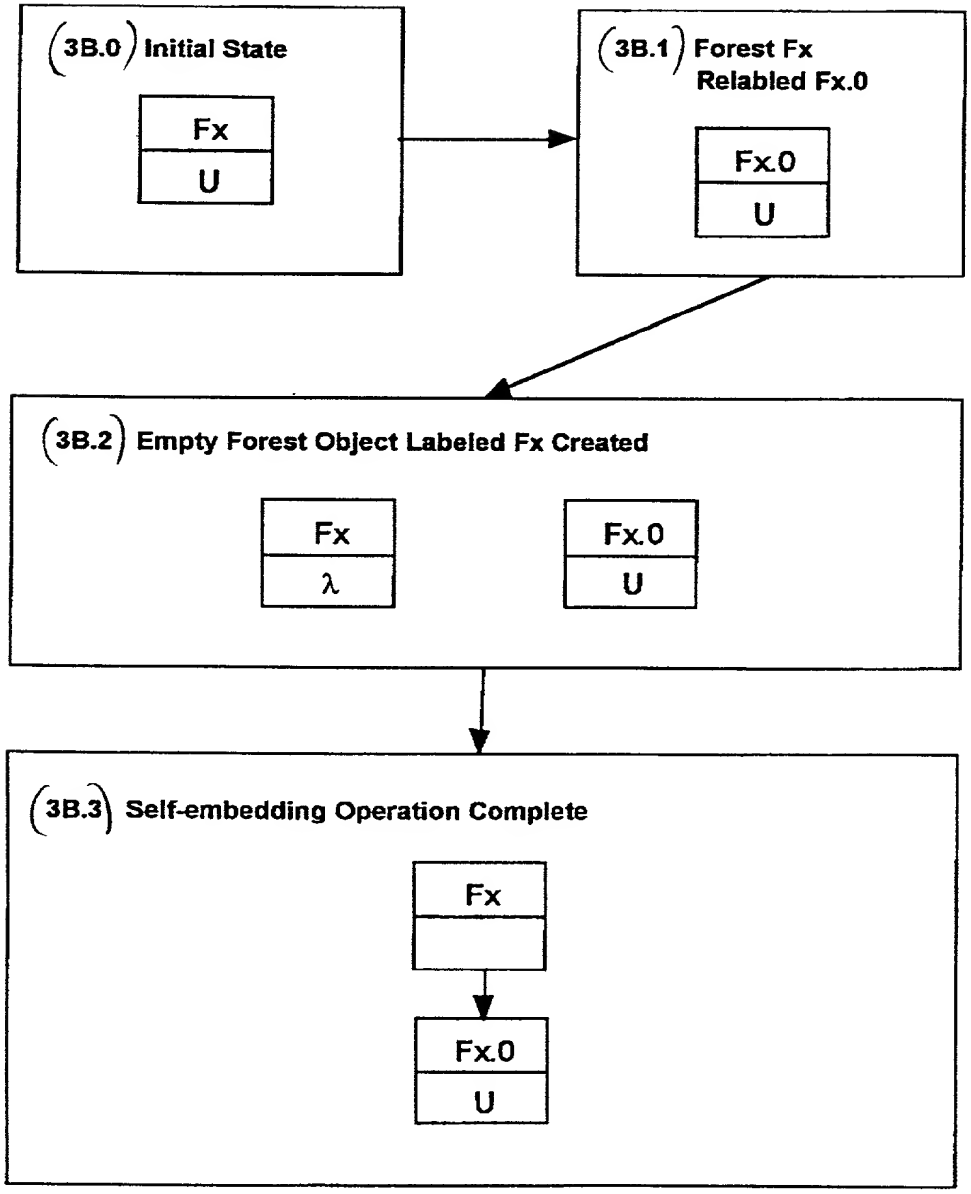

(3B.0) Initial State
Fx
U
(3B.1) Forest Fx
Relabled Fx.0
Fx.0
U
(3B.2) Empty Forest Object Labeled Fx Created
Fx
λ
Fx.0
U
(3B.3) Self-embedding Operation Complete
Fx
Fx.0
U

FIG. 3B

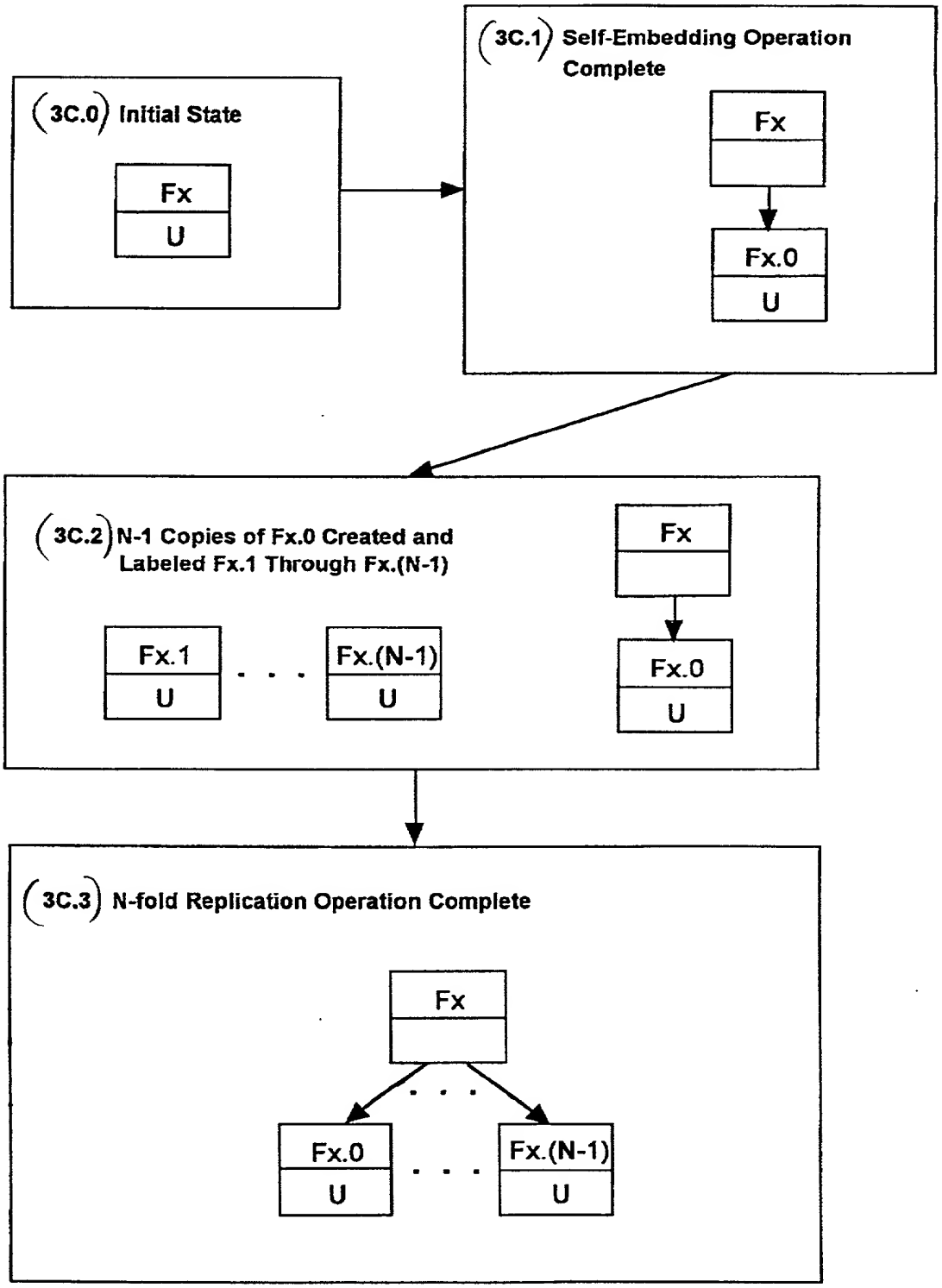

3C.0 Initial State
Fx
U
3C.1 Self-Embedding Operation Complete
Fx
Fx.0
U
3C.2 N-1 Copies of Fx.0 Created and Labeled Fx.1 Through Fx.(N-1)
Fx.1
U
Fx.(N-1)
U
Fx
Fx.0
U
3C.3 N-fold Replication Operation Complete
Fx
Fx.0
U
Fx.(N-1)
U

FIG.3C

FIG. 4

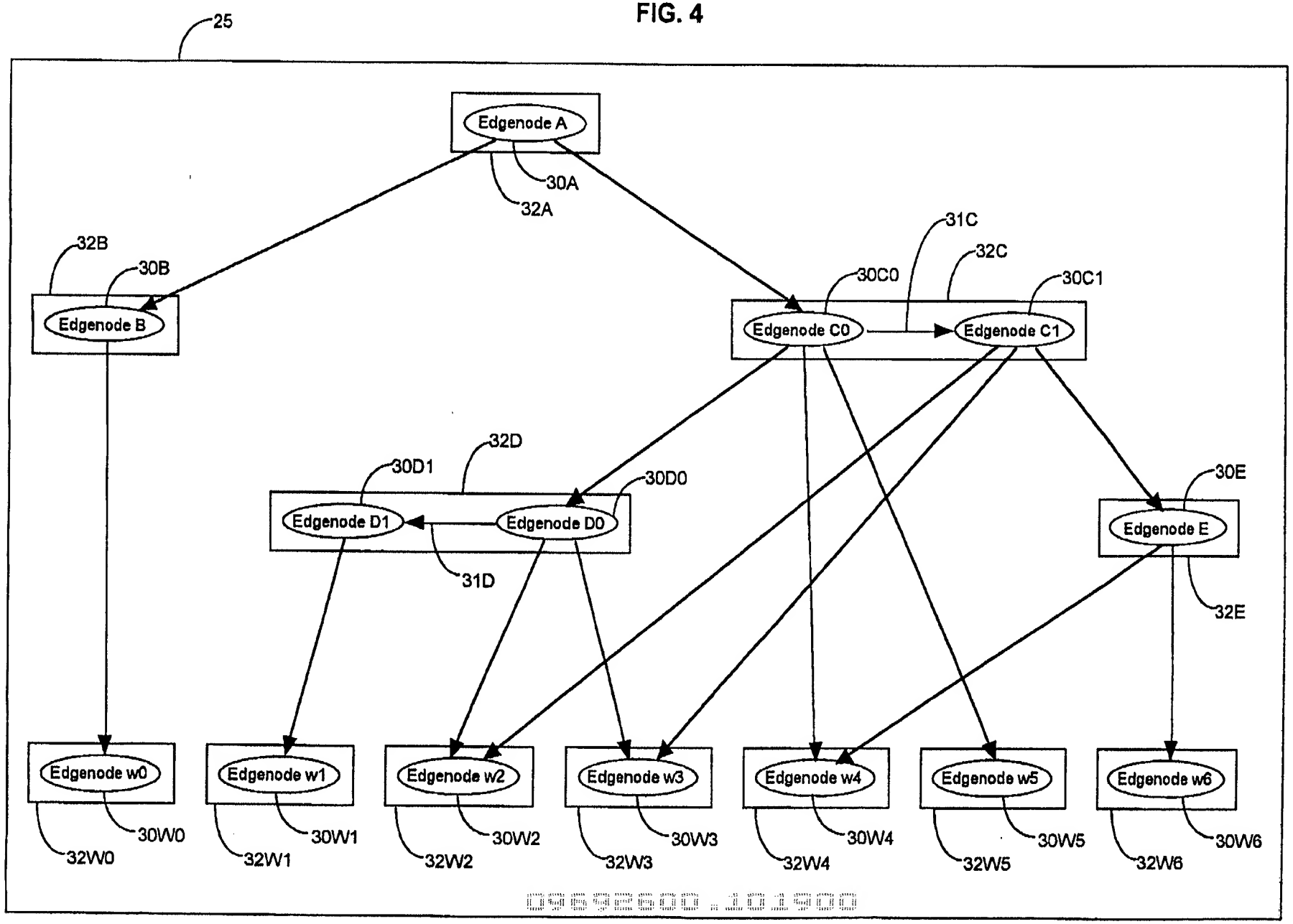

25
Edgenode A
30A
32A
32B
30B
Edgenode B
31C
32C
30C0
30C1
Edgenode C0
Edgenode C1
32D
30D1
30D0
Edgenode D1
Edgenode D0
31D
30E
Edgenode E
32E
Edgenode w0
Edgenode w1
Edgenode w2
Edgenode w3
Edgenode w4
Edgenode w5
Edgenode w6
30W0
30W1
30W2
30W3
30W4
30W5
30W6
32W0
32W1
32W2
32W3
32W4
32W5
32W6

FIG. 5

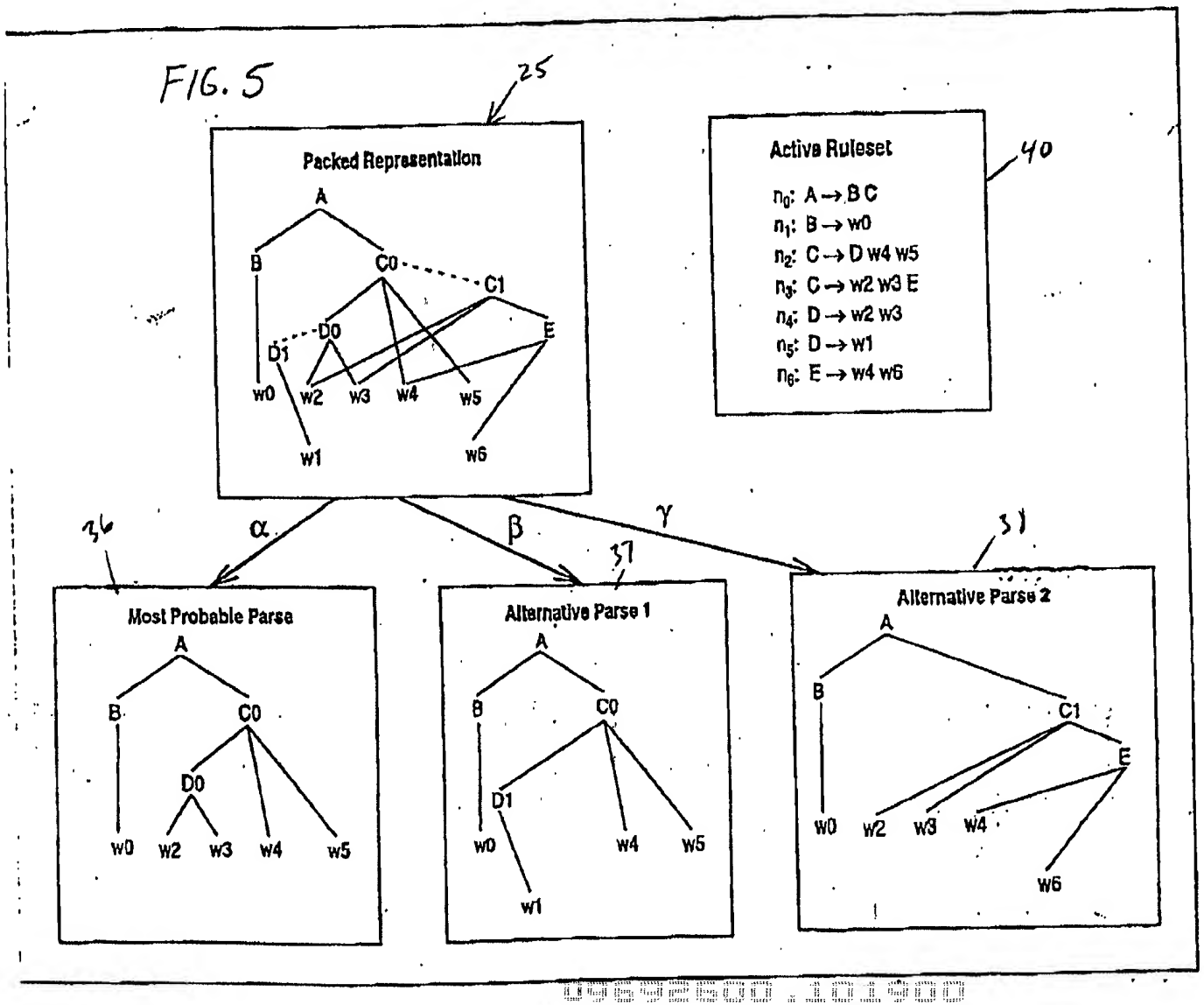

25
Packed Representation
A
B
C0
C1
D0
D1
E
w0
w2
w3
w4
w5
w1
w6
Active Ruleset
40
$n_0$: A → B C
$n_1$: B → w0
$n_2$: C → D w4 w5
$n_3$: C → w2 w3 E
$n_4$: D → w2 w3
$n_5$: D → w1
$n_6$: E → w4 w6
α
β
γ
36
37
31
Most Probable Parse
Alternative Parse 1
Alternative Parse 2

Figure 6: Traversal Algorithm for Unpacking Parses

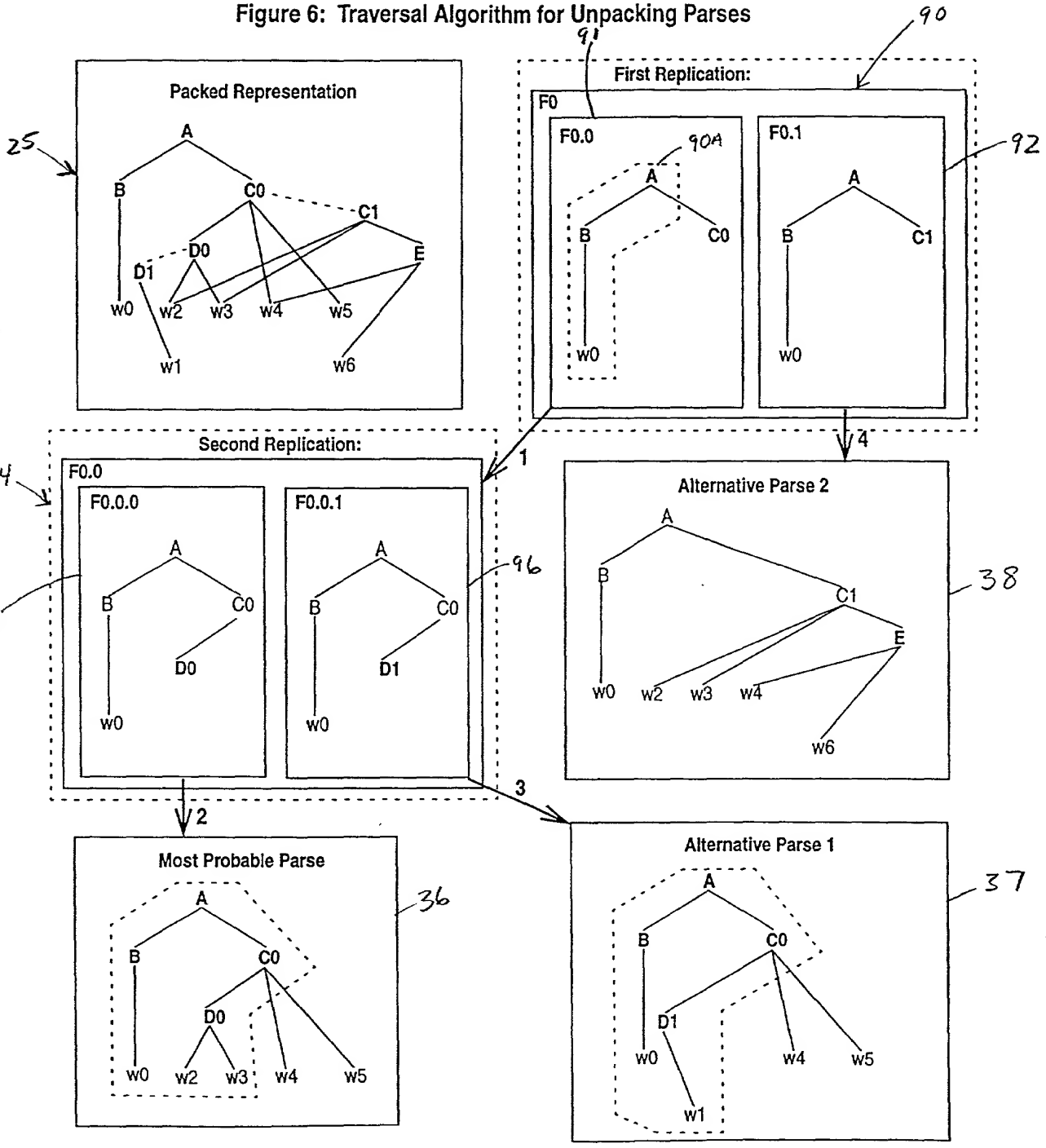


FIG. 7

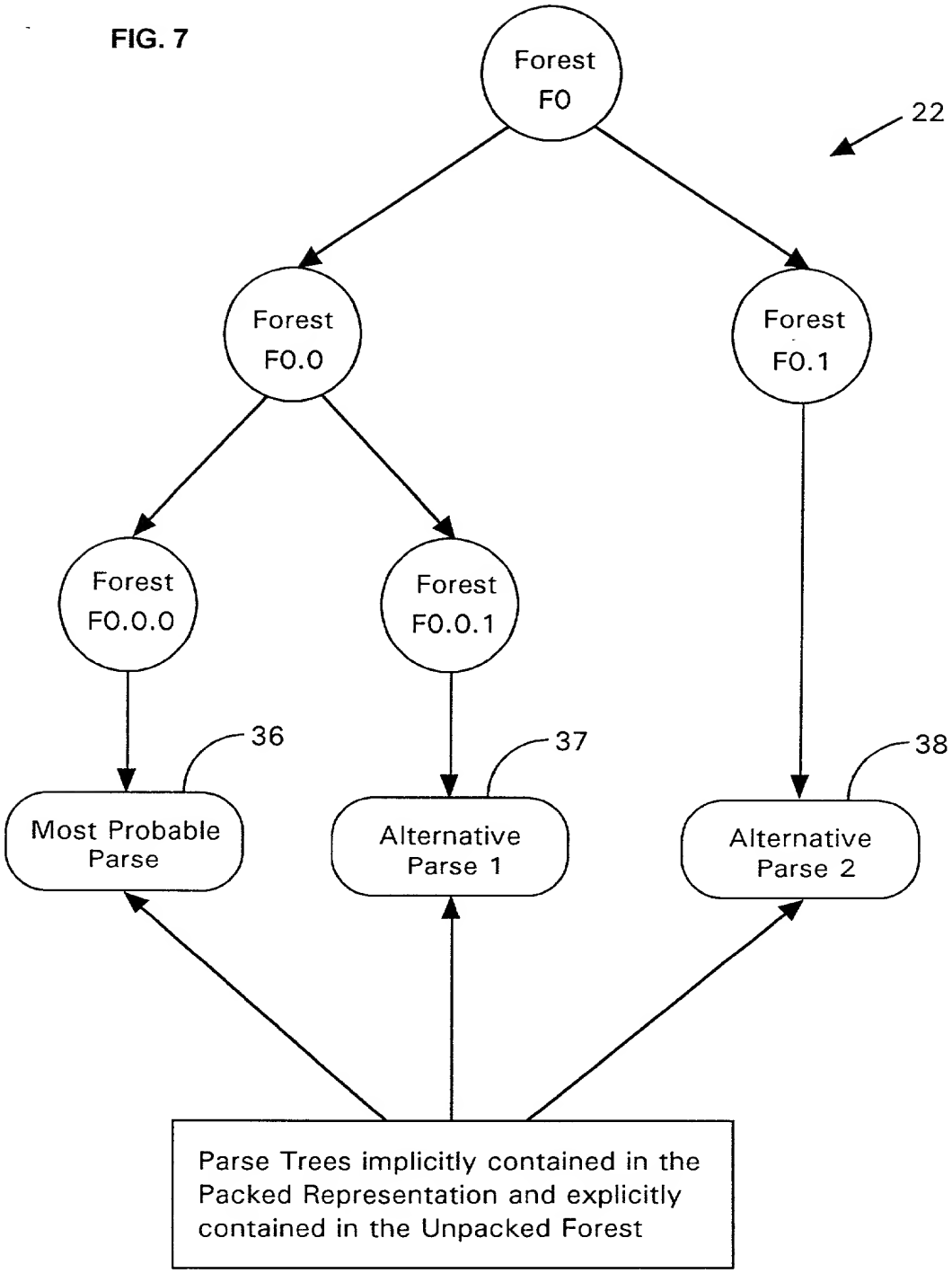

Forest
F0
22
Forest
F0.0
Forest
F0.1
Forest
F0.0.0
Forest
F0.0.1
36
37
38
Most Probable
Parse
Alternative
Parse 1
Alternative
Parse 2
Parse Trees implicitly contained in the
Packed Representation and explicitly
contained in the Unpacked Forest

FIG. 8

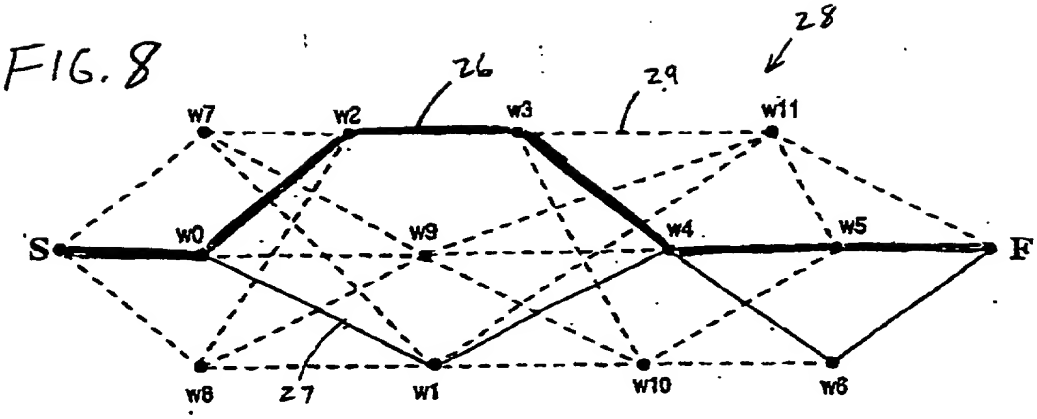
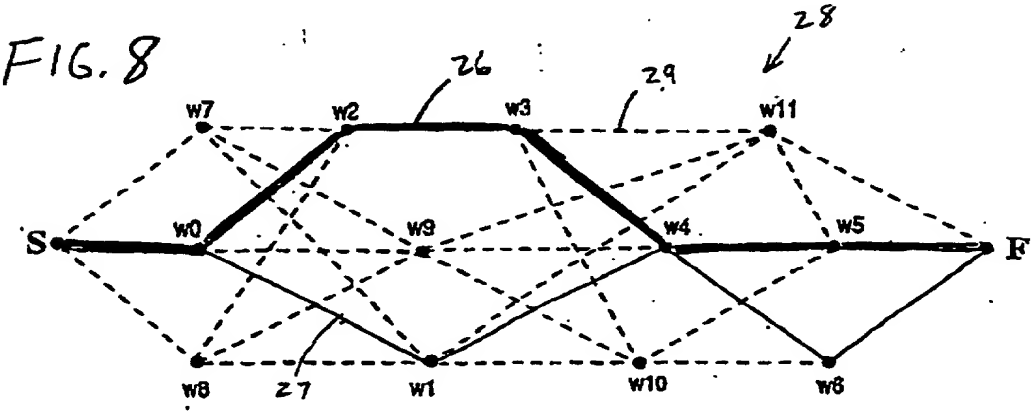


FIG. 9

FIG. 8



# PATENT APPLICATION DECLARATION
# COMBINED WITH POWER OF ATTORNEY

Attorney's Docket No.: CAS0014

☒ Regular (Utility) ☐ Design Application

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

SYSTEM AND METHOD OF DECODING A PACKED REPRESENTATION OF MULTIPLE PARSES

the specification of which:

☒ is attached hereto ☐ was filed on: _____
as U.S. Serial No.: _____
and was amended on _____
*(if applicable)*

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with 37 CFR § 1.56(a).

I hereby claim foreign priority benefits under 35 U.S.C. § 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate or 365(a) of any PCT international application which designated at least one country other than the United states of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s):

☒ no such application(s) filed ☐ such application(s) identified as follows:

| Application Number | Country | Date of Filing *(day, month, year)* | Priority Claimed |
|---|---|---|---|
| | | | ☐ Yes ☐ No |
| | | | ☐ Yes ☐ No |

I hereby claim the benefit under 35 U.S.C. §119(e) of any United States provisional application(s) listed below:

Provisional Application Serial No.: _____

Provisional Application Filing Date: _____

I hereby claim the priority benefit under 35 USC §120 of any United States application(s), or 365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 USC 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

Prior U.S. Application(s):

☒ no such application(s) filed

☐ such application(s) identified as follows:

| U.S. Parent Application No. or PCT Parent No. | Filing Date *(day, month, year)* | Status *(Patented, Pending, Abandoned)* |
|---|---|---|
| | | |
| | | |

AS A NAMED INVENTOR, I HEREBY APPOINT THE FOLLOWING REGISTERED ATTORNEY(S) OR AGENT(S) TO PROSECUTE THIS APPLICATION AND TO TRANSACT ALL BUSINESS IN THE PATENT AND TRADEMARK OFFICE CONNECTED THEREWITH:

**CUSTOMER NUMBER 22917**

Send correspondence to Customer Number **22917**

Address all telephone calls to:
James E. Gauger at (847) 576-0065
Fax (847) 576-3750

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 USC and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of first-named or sole inventor WILLIAM THOMPSON

Inventor's signature _____ Date _____

Residence EVANSTON (City) IL (State or Foreign Country)

Citizenship USA (Country)

Post Office Address 825 FOREST AVENUE, APT. 1I (Street Address)

EVANSTON (City) IL (State or Country) 60202 (Zip Code)

Full name of second-named joint inventor ANDREW WILLIAM MACKIE

Inventor's signature _____ Date _____

Residence SCHAUMBURG (City) IL (State or Foreign Country)

Citizenship USA (Country)

Post Office Address 2409 CREEK BEND ROAD #204 (Street Address)

SCHAUMBURG (City) IL (State or Country) 60173 (Zip Code)